Frugal Sensing: A Novel approach of Mobile Sensor Network Localization based on Fuzzy-Logic

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Figure 1: Seattle Mariners at Spring Training, 2010.

ABSTRACT

The Node localization problem in the mobile sensor network gains much attention. Recently, parametric point selection adopted from the Loop division has produced great positioning accuracy in conventional settings. However, a state of the art solution suffers significantly when used in mobile-based network distinguish by a high degree of radio signal irregularity. Therefore, a novel localization algorithm is required to address these challenges. We have proposed a new localization scheme by deploying sensor motivated by frugality. The distance is computed by received signal strength (RSSI) in which localization is measured as a fuzzy multilateration scheme with the help of mobile anchor deployment. RSSI and the signal power is used as an input in a fuzification. The fuzzy toolbox of Matlab is used in the entire simulation process and compared with the state-of-the-art techniques. The simulation results demonstrate an overall improvement of 60 to 70 percent in the presence of high signal irregularity.

*Both authors contributed equally to this research.

CCS CONCEPTS

• **Networks** → **Network Algorithms**; *Network protocols*; Network Services; Network reliability; • **Mathematics of Computing** → Probabilistic inference problems; Stochastic processes.

KEYWORDS

Frugal sensing, fuzzy-logic, membership function, mobile anchor, localization

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1 INTRODUCTION

Wireless sensor networks (WSNs) are increasingly a part of the modern landscape. Many applications like healthcare [1] and disaster response [2] benefited from the addition of sensing and networking. So, the common requirement of many WSNs systems is positioning and localization, where sensor nodes needed to discover their position according to the system design [3, 4]. A localization is very simple in many cases where, some nodes covering small area, required a single hop communication and fixed number of gateways are involved [5]. However, in certain environments localization is very hard to compute. The solutions like Global Positioning System (GPS) are rendered infeasible due to consumption of a lot of power, inaccuracy due to obstacles and indoor environment, and requirement of large size for installation of GPS modules in sensor nodes [6]. In order to solve localization problem, extensive research has been carried out to estimate position of sensor nodes with great accuracy. Various algorithms have been proposed that are classified on the basis of range-free or range-based, distributed or centralized, static or mobile anchors etc. Most of these algorithms target only accuracy while estimating position of sensor nodes. Since, sensor nodes contain scarce energy resources, so localization should also focus on minimizing energy consumption for enhancing lifetime of the network. Same like GPS fails in indoor environment, RSS based techniques also gives inaccurate results in presence of high degree of RF interference. The technique presented in [7] is based on RF time difference of arrival (TDoA) quickly degrades the accuracy as distances increased. Interferometry based localization provides high accuracy in [8] but fails in multipath environments.

To overcome these challenges mobile anchor based localization is a best solution in dense environment but mobility also make localization problem more complicated since node to node distance is keep changes which also leads solution to small-scale fading. Each multipath wave have an apparent shift in frequencies i.e., the Doppler shift because of relative motion between mobile anchors, which is directly proportional to the velocity of mobile anchor and direction of arrival [9]. Furthermore, due to environmental changes a mobile node experiences a time varying Doppler shift because of mobility and frequency shift on multipath components. Consequently, an environment affected due to multipath fading and mobility, the localization problem become more challenging and hence requiring a novel solution.

Fuzzy logic provides a robust and inexpensive way to deal with highly complex, noisy and uncertain environment. A well-known fuzzy-logic system to address the noisy channel is presented in the Sendai railroad [10], which incorporate the noisy data related to rail conditions, weather and train weight. Fuzzy-logic is also applied to the WSN localization in a same context. The empirical measurement is made between the mobile anchors participating in a centroid computation. Fuzzy inference systems (FIS), then used these measurements to produce fuzzy inference rules, which interpret RSSI and signal power as an input. The output of FIS is to recovers the actual distance, and hence compute the localization error. The contribution of the paper are as follows:

- We articulate the mobility of anchor node localization for noisy environment, as a fuzzy inference progression.
- We propose a fuzzy logic objective function for weighing coordinates of mobile anchors.
- We derived a fuzzy multilateration, as a part of FIS, which helps to compute the actual distance, from noisy RSSI data.
- We proposed a membership function as a weight of a fuzzifire which helps to measure the output function through defuzzifier.
- We accomplish extensive simulations and compare the proposed solution with state-of-the-art localization schemes.

The rest of the paper is organized as follows. Section 2 describes the motivation and background. The problem formulation and detailed algorithm explained in Section 3 and 4. We discuss the simulation and results in Section 5 and conclusion in Section 6.

2 MOTIVATION AND BACKGROUND

This work is motivated by our interest in positioning algorithms especially for mobile based network. We are also inspired by the sensor deployment motivated by frugality, i.e, the utilization of system resources for both static and mobile based network. We are also motivated from the interesting and surprising results obtained from simulation and derivation of two state-of-the-art localization techniques, namely PLD [11] and SNA [12]. From the derived scenarios we have decided to developed a framework which provides accurate localization even in presence of noise and harsh environment.

In [13], author proposed an innovative localization algorithm which determine the nonlinear signal, and correlation between two distances. There is an uncertainty factor for mobile anchor and the geometry factor on which the least square method is used to compute the position of the unknown node. A time based approach to determine the localization is presented in [14], which used an interval scheme define on the basis of sensor and mobile anchors. Furthermore, the distance between mobile and beacon node is computed through RSSI measurement. To do so, beacon nodes keep transmitting the signals to all other nodes in a network. The interval is then managed between the broadcasted signals which record the start time, which helps to determine the propagation time. This method don't perform any time synchronization which then adopted in [15] to trace the mobile target.

In another study of mobile based localization algorithm the position is computed inside a room by using radio waves [16]. This scheme was proposed to be novel in harsh environment and don't require any extra hardware except radio signal emitters. It was proposed to adopted relative values of RSSI between the nodes and maintain continuous mobility. In fact, the real mobility on this scheme was implemented in [17], which combines the characteristics of hop-distance measurements and back-off broadcast algorithm. A trajectory prediction/ path-planning is also a main concern while implemented a mobility scheme. A Gaussian mixture model based path planning is proposed in [18], which used data-centralized trajectory model that is complex in nature and hard to derived by a single Gaussian process. An extended kalman filtering based framework was implemented by [4] for rough and noisy environment using parametric point refinement.

3 PROBLEM FORMULATIONS

The challenges describe above were further motivate us to derived an accurate range-free localization algorithm. We have proposed a localization problem as a fuzzy inference problem using RSSI to compute the distance between mobile anchor node and unknown sensor nodes. The distance in fuzzy inference is expressed as a "High", "Medium", or "Low" and range is measured by the local RF environment with derivation of fuzzy rules based on available system information such as signal power and RSSI. In an ordinary system the node location is expressed by (X, Y, Z) coordinates in a 3D system. The (X, Y, Z) are used as a fuzzy members and fuzzy location bounded by the area where the probability determination of position is very high as shown in figure 2 [19]. Fuzzy set theory modified the node coordinates and maintain a *fuzzy set* consisting of *membership function* μ satisfying the degree relationship i.e.,

$0 \le \mu(x) \le 1$ with x as a crisp number obtained from fuzzy set. $\mu(x)$ denoted the *triangular membership function* expressed as follows.

$$\mu(x) = \begin{cases} 0 & if x < a \\ (x-a)/(b-a) & if a \le x \le b \\ (c-x)/(c-b) & if b \le x \le c \\ 0 & if x > c \end{cases} \quad (1)$$

where (a,b,c) is a triangular bin taken as a membership function.

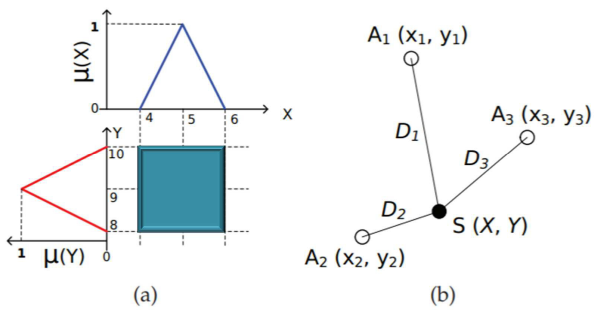

Figure 2: (a) Fuzzy location in triangular membership function and (b) Sensor node S in 2D plane along with anchor nodes in centroid form

A set of wireless sensor nodes are deployed randomly in a 3D space and establish an adhoc topology. The network establishing a graph with M mobile anchors and N sensor nodes i.e., $\sum(N, M)$ as shown in figure 3a further satisfying the following relations.

$$(X_i, Y_i, Z_i) \in \mathbb{R}, i \in 1, 2, 3, ..., N \quad (2)$$

$$(X_j, Y_j, Z_j) \in \mathbb{R}, j \in 1, 2, 3, ..., M \quad (3)$$

The anchors are moving along a predefined path and keep sending beacons to other static nodes and compute RSSI and euclidean distance D_{ij} i.e., $D_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2}$.

4 ALGORITHM DESIGN

The proposed algorithm executed in the form of four phases as described below:

4.1 Training Phase

This is the calibration or mapping phase to obtain the function data that would give us distance between transmitting node and receiving node from information of RSSI to be used in next phase. The phase kicks off when mobile anchor nodes start moving in random walk way to cover the entire WSN. During their motion, they transmit beacons for some time period and also make themselves available for rest of the time for receiving beacons from other mobile reference anchors. The message signal will be encoded in the following form of radio signals with proper modulation technique like Amplitude, Phase, or Frequency as shown in figure 3b.

Since the location of reference anchors are predetermined, so parameters of received signals could be easily correlated to the distance between transmitting node and receiving node. We have opted RSSI as signal parameter to map against distance. Each anchor node maintains a table of received RSSI from other anchors measured against respective distances. Once training phase is completed after motion of anchor nodes has covered entire WSN, the mapping tables are exchanged with one another along for finding the required interpolation function Γ. All the mobile anchor nodes have some sample mapping of RSSI versus distance. After training phase is completed a matrix of mapping function is shared between the anchor nodes

$$D_{est} = \Gamma(RSSI) = a_n RSSI^n + a_{n-1} RSSI^{n-1} + ... + a_1 RSSI + a_0 \quad (4)$$

$$D_{est} = \Gamma(RSSI) = \sum_{i=0}^{n} a_i RSSI^i \quad (5)$$

where Γ is a mapping function gain through interpolation of nth order i.e., $a_i, i \in [1, N]$ coefficient with $n > 3$ and D_{est} is an estimated distance. A fuzzy distance between node and mobile anchor is required in fuzzy inference system, which provide a crisp RSSI value obtained in beacon transformation phase. Some fuzzy rules are mapped i.e., (1) if RSSI is medium the distance will also be medium and (2) the distance will be larger if RSSI is weak. These two rules will further define the mapping strategies to compute the fuzzy distance.

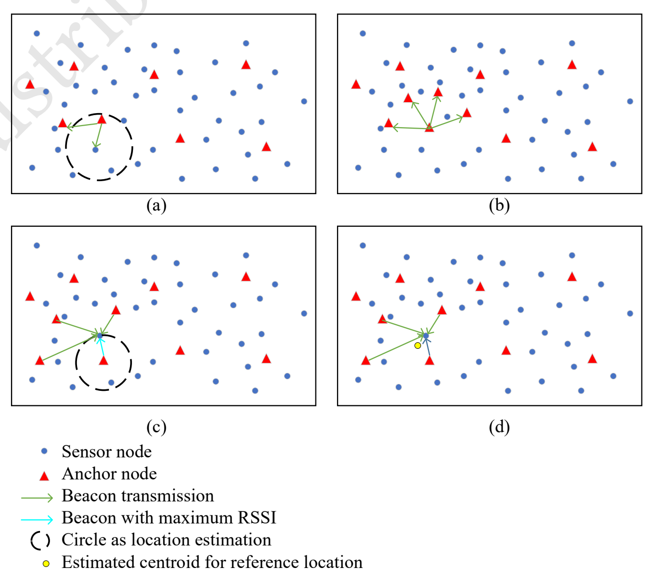

Figure 3: (a) Reference Anchors and Unknown Nodes Plot with Radio Range (b) Training Phase (c) Position Estimation in a radio Circle (d) Estimated Centroid Location

4.2 Position Estimation within a Circle

The data obtained from training phase as function Γ is applied in this phase. The reference anchor nodes move along their random walk method while transmitting beacons containing their coordinates and the mapping function Γ. The unknown nodes will receive the beacons and find the value of estimated distance from received RSSI. The maximum value of RSSI is used to draw circle with center as reference location from where maximum RSSI is obtained and radius as estimated distance mapped to maximum RSSI. This circle will contain unknown node but the exact position is uncertain as shown in figure 3c. It will be found in last phase. The random walk of a mobile anchor is modeled as follows.

$$\hbar(t) = \mp(X_j(t), Y_j(t), Z_j(t)) \in \mathbb{R}, j = 1, 2, ..., M \quad (6)$$

where $\hbar$ is a function to derived a random walk of location $\mp$ and t is a time constraints which is used to expressed the mobile anchors dynamic behavior. At this stage unknown nodes compute the maximum RSSI which they received from K mobile anchors.

$$RSSI_{imax} = max(RSSI_1, RSSI_2, ..., RSSI_K) = max \sum_{i=0}^{K} RSSI_K \quad (7)$$

4.3 Position Estimation as Extended Weighted Centroid

In this phase, the unknown nodes use reference anchors' beacons to find centroid with the help of weighted fuzzy functions. The basic form of fuzzy function is 3. Rough estimate of location of unknown nodes is computed using Centroid method with modification that the location of reference anchor nodes will be weighted by Fuzzy Logic based objective functions. It contains two membership functions μ_1, μ_2 for fuzzification of input variables. We have selected received Signal Power and received RSSI as input fuzzy parameters. The first function μ_1 maps received Signal Power to a specific number as follows:

$$\mu_1 = \begin{cases} 0(Low) & P_R \in [0, P_{Rmax}/3] \\ 1(Medium) & P_R \in [0, P_{Rmax}/3, 2P_{Rmax}/3] \\ 2(High) & P_R \in [2P_{Rmax}/3, P_{Rmax} \end{cases} \quad (8)$$

where P_R refers to the received signal power at the unknown node. The fuzzy levels 0, 1 and 2 for different ranges of Received Signal Power and they are scaled as *Low*, *Medium*, and *High*. Similar set of fuzzy function is set for received RSSI as follows:

$$\mu_2 = \begin{cases} 0(Low) & RSSI \in [0, RSSI_{max}/3] \\ 1(Medium) & RSSI \in [0, RSSI_{max}/3, 2RSSI_{max}/3] \\ 2(High) & RSSI \in [2RSSI_{max}/3, RSSI_{max} \end{cases} \quad (9)$$

The output function Υ defuzzifies the fuzzy functions. It provides the quality factor as weight for multiplying them with coordinates of reference locations for a certain unknown node.

$$\Upsilon \in [0, 1] for \mu_1, \mu_2 \in [0, 2]$$

(10)

The value of the output function varies between 0 and 1. Its value depends on levels of its input variables μ_1 and μ_2 which defines the fuzzy inference rules. For instance, if $\mu_1 = 0, \mu_2 = 0$ then $\Upsilon = 0$. Rules can be developed to map input fuzzy levels to output value in the given range. The estimated centroid will be obtained from the following equation:

$$(X_i, Y_i, Z_i)_{est} = \frac{1}{K}(\sum_{j=1}^{k}[\Upsilon, (X, Y, Z)]_j \quad (11)$$

It is evident that the fuzzy output provides suitable weights to anchor locations based on their RSSI, and received power.

Algorithm 1 Localization algorithm

Data: Beacons transmitted by mobile anchor nodes
Result: Localization coordinates of unknown nodes

Initial random deployment of sensor nodes.
Initial random deployment of mobile anchor nodes along with random walk.
stage 1: Training phase
while $j = 1 : N$ **do**
  Transmit/ receive beacons
  Obtained RSSI between anchor (i,j) as a distance.
  Find interpolated function that finds distance for given RSSI.
end while
stage 2: Position estimation in a radio circle
for n=1:N **do**
  while Unknown Nodes Not Received Beacons, $i = 1 : N$, mobile beacons $\neq = K$ **do**
    Keep sensing radio frequencies in passive mode.
    Obtained RSSI between anchor (i,j) as a distance.
    Find interpolated function that finds distance for given RSSI, Estimate distance from RSSI through Γ.
  end while
  Set $RSSI_{max}$ to very low initial value
  Generate weight Gaussian noise
  Obtain RSSI between unknown node n and mobile anchor K
  Obtain signal power between n and k with noise.
  if $RSSI(1, m) > RSSI_{max}$ **then**
    Set $RSSI_{max} = RSSI(1, m)$
    $max_m = m$
  end if
end for
Draw a circle between n and k
stage 3: Fuzification
Fuzzy inference, Inputs (RSSI with noise and signal power with noise), output(weighted values)
for k=1:K **do**
  Initialize $(X, Y, Z)_{iest}$
  Initialize sum of weight and membership function μ_1, μ_2
  Initialize $(X, Y, Z)_{iest}$
end for
stage 4: Error estimation
Computation of localization error using centroid abnd using weight as a weight centroid formula

4.4 Localization estimation

We have two assumptions to estimate the exact position of unknown nodes.

- Circles with center at location of anchor location that provides maximum RSSI for the given unknown node.
- Centroid using weighted average of locations of references anchors in radio range of unknown sensors.

These two raw location estimations will provide us the final solution to the localization problem. For this purpose, we draw a line segment that connects the centroid with the circle such that length of the line segment is minimum. The line segment will intersect circle at the point for which its distance from centroid is minimum. Let that point on the circle has coordinates $x_{min}, y_{min}, z_{min}$. Then location of unknown nodes will be:

$$(\hat{X}_i, \hat{Y}_i, \hat{Z}_i) = \frac{1}{2}(x_{iest} + x_{min}, y_{iest} + y_{min}, z_{iest} + z_{min}) \quad (12)$$

Finally accurate location of unknown nodes is found as the center point of the perpendicular bisector drawn from rough estimated location to circle drawn previously. The reference anchor nodes are mobile and adopt random-walk pattern. This scheme provides reasonable accuracy as compared to some notable range-free schemes based on weighted centroid algorithms. The detailed algorithm 1 explained the entire scenario.

5 SIMULATION AND RESULTS

In this section we will check the performance analysis of our proposed technique. Fuzzy logic system is more practical framework as compared to others involved mathematical modeling. The MATLAB software with Fuzzy toolbox is used to check the validation of the technique over $(1000 \times 1000 \times 1000)m$ area and $200 - 400$ unknown nodes and $30 - 40$ anchor nodes along with a communication range of $1.2m$. The weighted factor for RSSI and signal power was interpolated by fuzzy logic inference system. We also vary the parameters of both sensor and mobile anchor nodes to check the validation of the proposed technique. The speed of the mobile anchor nodes is not considered as we are moving all nodes on a fixed trajectory and speed is to be considered as constant. Time between the mobile anchor movement is also constant to avoid any collision.

In our experiments, we vary parameters of both the sensor network and sensor nodes, and of the MCL algorithm.

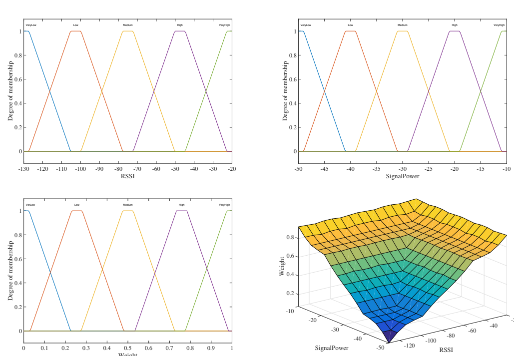

Figure 4: (a) Fuzzy input RSSI (b) Fuzzy input signal power (c) Fuzzy output weight (d) Fuzzy inference weighing system

The input variable RSSI and signal power and output weight variable and fuzzy weighing inference system is shown in figure 4. The fuzzy logic controller obtained the crisp RSSI values and used it as a membership function where these values are mapped between 0 and 1. Crsip values are converted to fuzzifier in fuzzification process and used to assign the weight. The initial simulation was run for 1000 times with an inital deployment of 60 sensor nodes. The overall average localization was recorded to $0.42m$ as shown in figure 5.

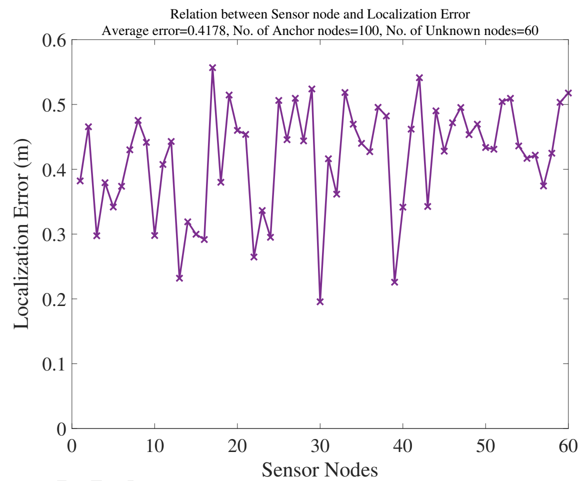

Figure 5: Average localization error vs number of unknown nodes

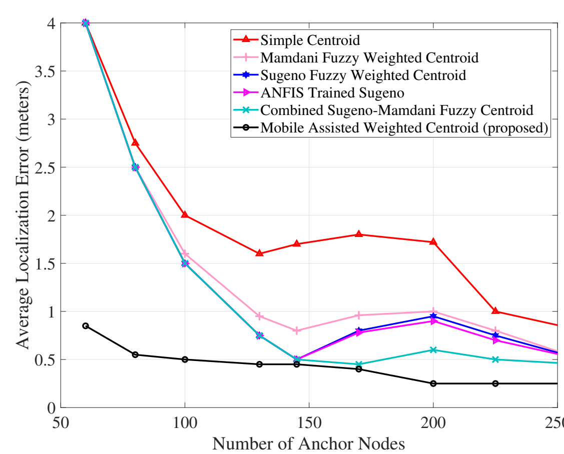

Figure 6: Average localization error vs number of unknown nodes

The proposed technique with fuzzy framework has been compared with many of the well-known algorithms. It is too be observed that even in case of simple centroid algorithm the localization error fluctuated because of weight in a division [20]. If the weight is 0 it means there are no mobile sensor node at present or the power is down due to node failure. In that case localization error can't be computed or gives very large error. This can be solved in fuzzy logic framework by using the weight in a fuzzy inference system (FIS). The Mamdani Suggano FIS also gives a higher localization error and high computation cost because at start all mobile anchor nodes are needed to self localized [21]. The proposed scheme is also being compared with some other techniques like ANFIS trained Sugeno and Combined Sugeno-Mamdani appraches which provide high accuracy as compared to other traditional schemes. Our approach still far better then all of those even using FIS system without the weight inclusion [22]. The RSSI is directly transform to weight satisfying the relation given in Equation 4.3 expressed in figure 7a.

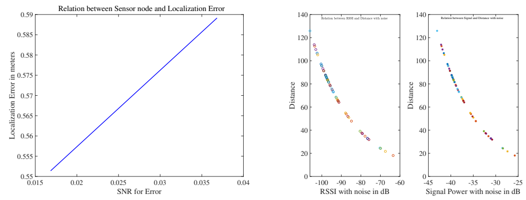

Figure 7: (a) distance vs error (b)

The anchors are deployed at random and grid topology in the different experiments. All nodes are assumed to have communication range which is 250 units. The average results of these experiments are elaborated in figure 7b. Radio irregularity and variability is actual RSSI patterns also have a substantial impact on the accuracy of the localization algorithm. The radius r assumed to be a perfect circle in our proposed technique so the error and accuracy can vary lightly in accordance with the environmental change and antenna irregularities. We also measure the communication overhead as a number of beacons transferred to each node in every localization process. The size of the packet is always same so, the average error is more functional as compared to how a message is parsed and encoded in the network. Sine the weight is parsed to FIS system therefore the computational capacity is a fixed variable in the entire localization process.

6 CONCLUSION

Many WSN applications requires to locate the position of the sensor node accurately and with low communication overhead. This is the first localization technique using fuzzy logic in presence of anchor mobility and static nodes which demonstrate the novelty of the proposed localization algorithm. The proposed technique is basically used the extended centroid approach and FIS. Data is being collected in training phase and then signal power and RSSI is parsed as an input to fuzzy system. The simulation experiments shows the high accuracy with a low communication overhead. Several issues remain to be addressed in future work including how the system works well in real implementation as well as how the system works in different mobile sensor network applications?. We are also looking into node sensitivity and density in a dense environment.

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REFERENCES

[1] V Sumathi. Wireless sensor network protocols, performance metrics, biosensors, and wsn in healthcare: A deep insight. In *Incorporating the Internet of Things in Healthcare Applications and Wearable Devices*, pages 86–108. IGI Global, 2020.

[2] Nei Kato and Song Guo. Guest editor's introduction: Special section on emerging technologies for disaster management. *IEEE Transactions on Emerging Topics in Computing*, 8(1):104–105, 2020.

[3] Prateek Raj Gautam, Sunil Kumar, Akshay Verma, Tarique Rashid, and Arvind Kumar. Localization of sensor nodes in wsn using area between a node and two beacons. In *Advances in VLSI, Communication, and Signal Processing*, pages 221–228. Springer, 2020.

[4] Tanveer Ahmad, Xue Jun Li, and Boon-Chong Seet. Noise reduction scheme for parametric loop division 3d wireless localization algorithm based on extended kalman filtering. *Journal of Sensor and Actuator Networks*, 8(2):24, 2019.

[5] Ping Wang and Gang Tu. Localization algorithm of wireless sensor network based on matrix reconstruction. *Computer Communications*, 154:216–222, 2020.

[6] Thu Nga Le, Peter HJ Chong, Xue Jun Li, and Wai Yie Leong. A simple grid-based localization technique in wireless sensor networks for forest fire detection. In *2010 Second International Conference on Communication Software and Networks*, pages 93–98. IEEE, 2010.

[7] Hüseyin Akcan, Vassil Kriakov, Hervé Brönnimann, and Alex Delis. Gps-free node localization in mobile wireless sensor networks. In *Proceedings of the 5th ACM international workshop on Data engineering for wireless and mobile access*, pages 35–42, 2006.

[8] Branislav Kusy, Janos Sallai, Gyorgy Balogh, Akos Ledeczi, Vladimir Protopopescu, Johnny Tolliver, Frank DeNap, and Morey Parang. Radio interferometric tracking of mobile wireless nodes. In *Proceedings of the 5th international conference on Mobile systems, applications and services*, pages 139–151, 2007.

[9] David Tse and Pramod Viswanath. *Fundamentals of wireless communication*. Cambridge university press, 2005.

[10] Hiroyasu Oshima, Seiji Yasunobu, and S-i Sekino. Automatic train operation system based on predictive fuzzy control. In *Proceedings of the International Workshop on Artificial Intelligence for Industrial Applications*, pages 485–489. IEEE, 1988.

[11] Tanveer Ahmad, Xue Jun Li, and Boon-Chong Seet. Parametric loop division for 3d localization in wireless sensor networks. *Sensors*, 17(7):1697, 2017.

[12] Tanveer Ahmad, Xue Jun Li, Boon-Chong Seet, and Juan-Carlos Cano. Social network analysis based localization technique with clustered closeness centrality for 3d wireless sensor networks. *Electronics*, 9(5):738, 2020.

[13] Chengming Luo, Wei Li, Hai Yang, Mengbao Fan, and Xuefeng Yang. Mobile target positioning using refining distance measurements with inaccurate anchor nodes in chain-type wireless sensor networks. *Mobile Networks and Applications*, 19(3):363–381, 2014.

[14] Ghalib A Shah and Ozgur B Akan. Timing-based mobile sensor localization in wireless sensor and actor networks. *Mobile Networks and Applications*, 15(5):664–679, 2010.

[15] Enyang Xu, Zhi Ding, and Soura Dasgupta. Target tracking and mobile sensor navigation in wireless sensor networks. *IEEE Transactions on mobile computing*, 12(1):177–186, 2011.

[16] Hirokazu Miura, Kazuhiko Hirano, Noriyuki Matsuda, Hirokazu Taki, Norihiro Abe, and Satoshi Hori. Indoor localization for mobile node based on rssi. In *International Conference on Knowledge-Based and Intelligent Information and Engineering Systems*, pages 1065–1072. Springer, 2007.

[17] Ya Li, Guangrun Wang, Lin Nie, Qing Wang, and Wenwei Tan. Distance metric optimization driven convolutional neural network for age invariant face recognition. *Pattern Recognition*, 75:51–62, 2018.

[18] Shao-Jie Qiao, Kun Jin, Nan Han, Chang-Jie Tang, and GL Gesangduoji. Trajectory prediction algorithm based on gaussian mixture model. *Journal of software*, 26(5):21–32, 2015.

[19] Harsha Chenji and Radu Stoleru. Toward accurate mobile sensor network localization in noisy environments. *IEEE transactions on Mobile Computing*, 12(6):1094–1106, 2012.

[20] Jun Wang, Paulo Urriza, Yuxing Han, and Danijela Cabric. Weighted centroid localization algorithm: theoretical analysis and distributed implementation. *IEEE Transactions on wireless communications*, 10(10):3403–3413, 2011.

[21] Monika Nanda, Ashok Kumar, and Sandeep Kumar. Localization of 3d wsn using mamdani sugano fuzzy weighted centriod approaches. In *2012 IEEE Students' Conference on Electrical, Electronics and Computer Science*, pages 1–5. IEEE, 2012.

[22] Ashok Kumar, Narottam Chand, Vinod Kumar, and Vinay Kumar. Range free localization schemes for wireless sensor networks. *International Journal of Computer Networks & Communications*, 3(6):115, 2011.